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An overview of development of tidal current in China: Energy resource, conversion technology and opportunities

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ABSTRACT

The world has been suffering dramatically increasing energy consumption during recent years. As the biggest developing country, China has a more urgent situation. To highlight the promising potential of renewable energy may be the only solution. Due to the vast sea area and continuous coast line of 18,000 km, China has an excellent tidal current energy resource, which has good prospect for development. In this paper, the development of tidal current in China is briefly reviewed. The description is focused on the tidal current energy resource and the status of conversion technologies in China. Finally, the opportunities of the development of tidal current in China, including the urgent energy situation, the increasing pressure on reducing emissions, national policies for tidal current energy development and the increase of investment, are discussed in detail. A conclusion is made that the tidal current energy ought to be an important option for China in terms of renewable energy.

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1. Introduction

Our world has been suffering dramatically increasing energy consumption during recent years. The same situation happens in China also. As one of the biggest developing countries, China not only enjoys the prosperity of rapid development, but also faces a series of problems caused by the increasing energy consumption (heavily dependent on fossil fuels), such as short supply of fossil fuels, pollution emissions and significant environmental issues.

One possible effective solution is to highlight the promising potential for renewable and sustainable energy resources, in the forms of wind energy, solar energy, hydropower, biofuels and ocean energy [1–3]. And these environmentally friendly resources have been considered as essential components of the national energy balance by our energy policy makers.

Oceans cover approximately 71% of Earth's surface and hold a large amount of energy more than 2×10^3 TW [4], which is the largest untapped renewable energy resource on the planet. Ocean energy is available in many different forms including tide, wave, tidal current, thermal, salinity gradients and biomass [5]. Among them, tidal current energy was highlighted because of the advantages including the high energy density (approximately 832 times greater than wind) [5], long-time predictability and potentially large resource [6]. Therefore, it is receiving more and more attention from politicians, industrialists and academics all over the world [7] and is expected to play a very important role in the future energy supplies.

China has an excellent tidal current energy resource with a capacity of approximate 13950 MW [8], which has been exploited since 1960s and taken on a new look with several universities taking part in this field recently. And there are several stimulative on the development of the tidal current energy, so it will have a promising prospect.

In this paper, the main subject is to take a closer look at the development of the tidal current energy in China. The first part of the paper, Section 2, describes the tidal current energy resource assessments in China. Then the status on the development of tidal current energy conversion technology in China is discussed in Section 3. Section 4 discusses the good opportunities of tidal current development in China. Finally, a conclusion is made in Section 5 that the tidal current energy might be a viable option as a renewable energy resource.

2. Tidal current energy resources in China

2.1. Causes of tidal current and its possible locations

We usually use a term, oceanic current, to describe the motion of the ocean water, which are driven by several factors as following [9]:

- The first factor is wind. Winds drive currents at or near the ocean's surface, near coastal areas on a localized scale or in the open ocean on a global scale.
- The second factor that drives currents is thermohaline circulation – a process driven by density differences in water due to temperature and salinity in different parts of the ocean. This movement can occur at both deep and shallow ocean levels with much slower velocity than tidal or surface currents [6].
- The third factor is the rise and fall of the tides, which is driven by the gravitational attraction of the sun and moon on Earth's oceans [6]. Tides create horizontal movements of water in the oceans, which are called "tidal currents". They usually occur near the shore, and in bays and estuaries along the coast and change in a very regular pattern, which means they can be predicted for future dates.

It should be noted that in this paper only tidal current in China is discussed unless otherwise indicated.

The tidal current energy available at any particular site is proportional to the fluid density and the cube of its velocity [10,11], so the velocity is evidently the most important feature affecting the potential of tidal current and it is one of the major concerns when assessing the resource of a given location.

Areas with high tidal current flows commonly occur in narrow straits, between islands, and around headlands [5]. These locations, where the tidal current velocity is enhanced because of a funneling effect, are general desired locations for deployment of tidal current energy [12]. In [13], the key criteria and some general principles for tidal current turbine site selection were discussed, and some of them are listed as follows:

- 2–3 m/s maximum spring peak current, in order to achieve an economic size of rotor;
- Uniform flow with strong currents for long periods to maximize power available;
- Close to coast;
- Channels or constrictions between islands;
- Headlands in the path of moderate flows;
- Estuaries or other resonant water volumes;
- Narrow entrances to enclosed tidal lakes.

2.2. Distribution of tidal current energy in China

China is situated in the west coast of the Pacific with a coastline of 18,000 km long as the crow flies (if including all the islands, the total length of the coast is 32,000 km), see Fig. 1. The coastline of China borders several oceans, which are Bohai Sea, Yellow Sea, East

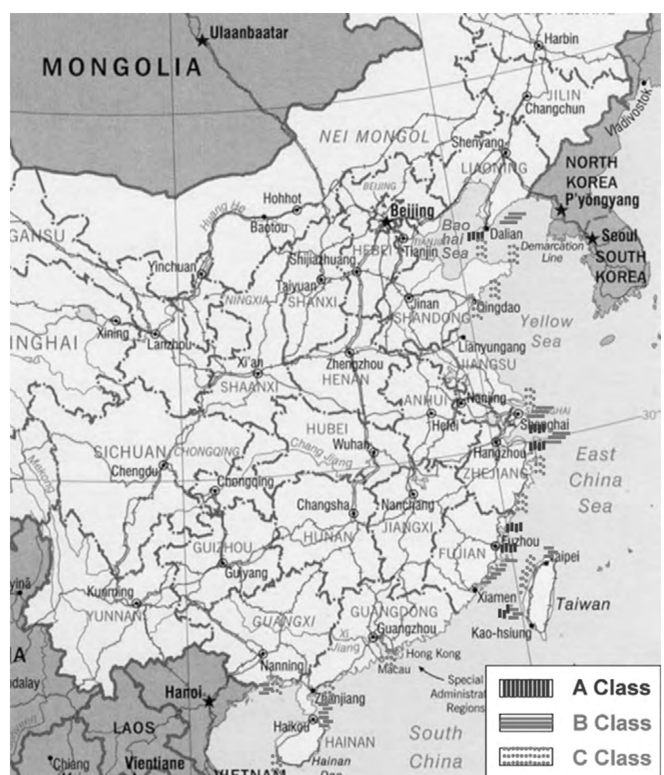


Fig. 1. Coast of China and distribution of tidal current energy resource.*Sources*: Adapted from Ref. [14,16].

China Sea and South China Sea respectively, from north to south. There are thousands of islands in these seas, of which 6500 islands have an area more than 500 m^2. Between these islands, there exist hundreds of channels, where the tidal current may be enhanced.

According to the estimation of the division of marine resource (tide, wave and tidal current) in China (EDMRC) by State Oceanic Administration and Ministry of Resources and Electric Power in 1989 [14], there is a highest velocity of tidal current in the coast of East China Sea, then the coast of Bohai Sean and Yellow Sea, and finally the coast of South China Sea, which can be seen in Fig. 1. More details are described as follows:

Coast of Baohai Sea: The tidal of Baohai Sea is dominated by the regular semi-diurnal tide and irregular semi-diurnal tide, with a velocity about 0.5–1.0 m/s. Bohai Strait, located between Liaodong Peninsula and Shandong Peninsula, is the eastern part of Bohai Sea and through which Yellow Sea is connected. The 90 km broad strait is separated into several channels by Miaodao Islands, from north to south, Laotieshan, Daqin, Xiaoqin, Beituoji, Nantuoji, Changshan and Dengzhou, as shown in Fig. 2. According to the guidelines mentioned in Section 2.1, the velocity of tidal flows in these channels is significantly increased, and Laotieshan is highlighted with a maximum velocity above 3 m/s, see Fig. 1.

Coast of Yellow Sea: The tidal of most areas of Yellow Sea coast is of regular semi-diurnal except coastal sea of Yantai and Bohai Strait, where is dominated by irregular semi-diurnal tide. There is higher velocity (about 1 m/s) in Yellow Sea than Bohai Sea. In the North Yellow Sea, the sites with high velocity of tidal current are located on coastal sea of Liaoning [14,15] and Bohai Strait mentioned above. In the Middle Yellow Sea, coastal sea of Chengshanjiao [16] and Zhaitang Island channel [17], have measured spring tidal current velocity of about 1.5–2.0 m/s. The research on the strong tidal current in South Yellow Sea (coastal sea of the Jiangsu) is scarce. However, in [18] several sites with strong tidal current were presented. One example is Qionggang-Tiaozini, where the measured velocity is above 2.5 m/s [19]. Other sites with strong tidal current in the South Yellow Sea, such as Doulonggang, Xiaoyangkou were presented in [16].

Coast of East China Sea: The coast of East China Sea is semi-diurnal tides dominated coastline, where has the strongest tidal current. There are several sites, such as Yangtse River mouth, Hangzhou Bay, Zhoushan Archipelago and some rivers (Minjiang, Jiaojiang) mouths in the coastal area of Zhejiang and Fujian, with measured velocity of tidal current approximately 3.0–4.0 m/s [16]. Among them, Zhoushan Archipelago has several channels with the strongest tidal current in China, as shown in Fig. 3 and can also be seen in Table 1.



Fig. 2. Bohai Sea and Bohai Strait.*Source:* Google Earth (4.2.0198.245).



Fig. 3. Location of Zhoushan archipelago.*Source:* Google Earth (4.2.0198.245).

Coast of South China Sea: The velocity of tidal current in South China Sea is less than 0.5 m/s in most areas [16]. The enhanced tidal current is located in Qiongzhou Strait, with peak flows over 2 m/s, caused by constrained topography between Leizhou Peninsula and Hainan Island. Furthermore, Zhujiang mouth and Beibu Bay have tidal current with velocity of 1.0–1.5 m/s. These sites can be found in Fig. 1 and Table 1.

2.3. Estimation of tidal current energy resources in China

There are many locations in China with high current velocities. According to EDMRC, about 13,950 MW of tidal current energy is technically available in 130 channels in China [8,14]. These channels are primarily located in the coastal area of China and can be divided into three classes in terms of the velocity of tidal flow, which are shown in Fig. 1 and Table 1. The statistical estimations of tidal current energy in provinces listed in Table 1 are presented in a histogram, Fig. 4. It can be seen from Fig. 4, Zhejiang province, which contributes nearly 50% of the total tidal current energy reserve, ranks first in China. Behind Zhejiang, Taiwan, Fujian, Shandong and Liaoning have theoretically available reserve of 2283, 1280, 1195 and 1140 MW, respectively, ranking 2nd to 5th. These provinces have some excellent channels with high power density. According to EDMRC, these channel are Laotieshan (Liaoning, 17.41 kW/m^2), Beihuangcheng (Shandong, 13.69 kW/m^2), Hangzhou Bay North (Zhejiang, 28.99 kW/m^2), Jintang (Zhejiang, 25.93 kW/m^2), Guishan (Zhejiang, 23.89 kW/m^2), Xihoumen (Zhejiang, 19.08 kW/m^2), Sandujiao (Fujian, 15.11 kW/m^2) and Yuweng Island (Taiwan, 13.69 kW/m^2), which are considered with better condition for tidal current energy development and highlighted in Table 1.

Actually, at present current measurements of China are scarce due to the lack of fund and the complicated circumstance. The most authoritative work in China mentioned above, EDMRC, involves 130 channels, while some channels with high velocity are

Table 1
Division of tidal current energy resources in the coastal area of China [14] (V_m: maximum velocity, m/s).

Province	Districts			Number of channels
	A class of district, $V_m \geq 3.06$	B class of district, $2.04 \leq V_m < 3.06$	C class of district, $1.28 \leq V_m < 2.06$	
Liaoning	Laotieshan		Changshandong, Guapi, Sanshan, Xiaosanshan	5
Shandong		Beihuangcheng	Miaodao archipelago, East coast	7
Shanghai		Beigang, Nancao	Hengsha, Beicao	4
Zhejiang	Xihoumen[a], Jitang[a], Guishan[a], Nanhui-Lvhua Hangzhou Bay mouth	Zhoushan channel[a], Jiaojiang mouth	Zhoushan channel, Xiangshangang, Sanmen Bay, Taizhou Bay, Leqing Bay	37
Fujian	Sandujiao[a]	Sandudao East[a], Haitan strait South, Minjiang mouth, Dazhuhangmen	Shachenggang, Xinghua Bay, Haitan strait	19
Taiwan		Penghu North[a], Penghu South, Taiwan North, Linshanbi North	Pescadores, Taiwan West, Sandiaojiao	35
Guangdong		Qiongzhou strait, Wailuo Channel	Zhujiang mouth, Yuexi coast	16
Guangxi		Zhenzhugang	Dafengjiang mouth, Longmengang, Fangchenggang	4
Hainan		Qiongzhou Strait East	Chengmai Bay mouth, Yinggehai	3

[a] Area with better condition for tidal current energy development.

excluded. One example is Zhaitang Island Channel, a channel in Shandong Province, where the mean peak tidal current is about 2m/s [17]. So, maybe a comprehensive tidal current resource survey involving more channels needs to be carried out, updating the existing tidal data.

Fortunately, recently years some numerical modeling work has been done by Chinese researchers regarding tidal flow along the China coast [17,20,21]. Lv et al. [21] used a numerical model known as Princeton Ocean Model (POM), developed by Alan Blumberg and George Mellor, to study the tides and three-dimensional tidal currents in Jiaozhou Bay. Song et al. [20] used finite-volume coastal ocean model (FVCOM), developed by UMASSD-WHOI joint efforts, to simulate the tide in Qingzhou Bay. Although these works were not originally intended for tidal current energy use, from their results concerning tidal current, some of the models ought to be suitable or at least adaptable to put to such use as well.

3. Tidal current conversion technology in China

The way to harvest the tidal current energy is to intercept the free flowing water and convert the kinetic energy into electricity, which has common characteristics to those being used in wind energy [22,23]. So the tidal energy conversion systems have become a focal point in the exploitation of tidal current energy. In [24] several interrelated concepts systems were described briefly and categorized in two broader classes, turbine systems (horizontal-axis turbine [25–30], vertical axis turbine [31–33], cross-flow system [34], Venturi system [35,36] and gravitation vortex system [37]) and non-turbine systems (flutter vane system [38,39], piezoelectric system [40], oscillating hydrofoil system [41] and sails system [42]). Both kind of conversion systems have been described and listed in a detailed table in [12]. The non-turbine systems, which are mostly devices with oscillating lift surfaces, are at the proof-of-concept stage, therefore the turbine systems, especially horizontal-axis turbine and vertical axis turbine are commonly recognized as the preferred choices for conversion of tidal current. Unlike other renewable energy resources with impact on the environment, such as huge wind turbine in wind energy [43], large reservoirs and dams in large hydro plants (including tide energy) [44,45], the use of tidal current turbine has minimum influence on the environment, although more research and data from full-scale offshore experiments are needed in order to make a definite conclusion [7]. However, at present, there are no turbine has been established and used in commercial sized tidal current farms due to their current stages of development [7,12].

In China, the origins of tidal current energy conversion can be traced back a long way, starting from 1958 in Shandong and Guangdong [46]. Then in 1969, another testing was carried out in Jiangsu, under the Changjiang Bridge [46]. In the late 1970s, a tidal current conversion testing, which was the most famous earlier study of tidal current energy in China, was carried out in Zhoushan (Zhejiang) [14]. The testing system consisted of two horizontal-axis turbines installed at the back end of a boat and a hydraulic transmission system, and harnessed 5.7 kW electricity at the velocity of 3 m/s. Since 2002, many high schools and institutes took part in the study of tidal current technologies. Among them, Harbin Engineering University (HEU), Northeast Normal University (NENU), Zhejiang University (ZJU) and Ocean University of China (OUC) have done outstanding works. In the following section, more details about their studies will be described.

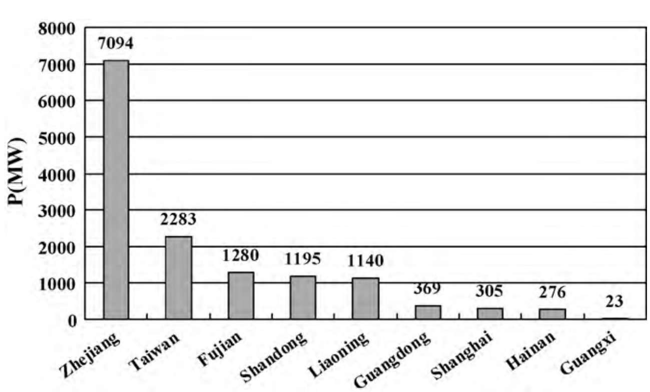


Fig. 4. Top nine provinces with tidal current energy resource in China [16].



Fig. 5. Floating tidal current power plant in GuiShan channel (70 kW, 2002, HEU).



Fig. 6. Gaoting seabed mounted tidal current power plant at Zhoushan (40 kW, 2005, HEU).

3.1. HEU

HEU is a pioneer of modern tidal current energy utilization in China, which has started its research on tidal current energy conversion since early 1980s. Based on the researches on the hydrodynamic characteristics of vertical axis turbine [47–52], it has carried out several prototype systems.

In January 2002, HEU installed the first floating moored tidal current turbine in China, a 70 kW prototype system (*WanXiang I*) in Guishan channel (Daishan, Zhejiang), as shown in Fig. 5. The device developed by HEU consists of dual vertical axis rotors, power train systems, control mechanism and floating platform. Each 2.2 m diameter rotor consists of four variable pitch foil vertical blades with 0.65 m chord and 2.5 m height. Thin spokes in tension connect the blades to the hub for the purpose of transferring torque. A shaft connects the hub to the gearbox coupled to the generator forming the power train systems. The rotors, power train systems and control mechanisms are supported by a floating platform, which is kept floating by a pair of hulls much like a catamaran. The floating platform then moored to the sea bed through a mooring system, which includes 4 gravity anchors and light chains [53,54].

In December 2005, the first seabed mounted tidal current system in China (*Wangxiang II*) with 40 kW rated power, was installed by HEU in a channel between Gaoting and Gangshan, as shown in Fig. 6. The system consists of twin 20 kW straight-blade vertical rotors, train system and support platform. The support system consists of turbine nacelle, caissons and fixed legs. As a totally submerged system, the power train system and generator are sealed well in the turbine nacelle [54].

A new project, a 150 kW system, is being conducted by HEU, Shandong Electric Power Engineering Consulting Institute, National Ocean Technology Center, PE-NERC and Gaoting Shipyard and supported by National Key Technology R&D Program (NKTRDP). The project is aimed at testing the prototype turbine and demonstrating technology, which will be finished in 2011.

3.2. ZJU

ZJU has started the investigation of "underwater turbine" in support of NSFC since 2005. In April 2006, a sea trial of 5 kW horizontal-axis tidal current turbine was carried out in Daishan, Zhejiang Province [55–57], as shown in Fig. 7(a). The design was subsequently developed further, and a sea trail of 25 kW device, which has three 2.2-m length blades, was carried out in May 2009 in Daishan, Zhoushan, as shown in Fig. 8(b). Results showed that the turbine worked well, generating a maximum power of 29.08 kW in a current of 2.4 m/s. It had good self-starting characteristics and can start rotating at 1.37 m/s. And it can also work well at low velocity, producing 1 kW of power from a water flow as low as 0.6 m/s [58].

3.3. NENU

NENU has also shown interest in tidal energy for many years [59]. In 2006, it developed a horizontal-axis turbine supported by National High Technology Research and Development Program ("863" Program), as shown in Fig. 8(a). With eight blades, the 1 kW device can generate greater starting torque, so it can work at relatively low velocity of flow. In 2008, an improved 2 kW device was tested in the coastal area of Qingdao, as shown in Fig. 8(b).

Now, a 20 kW horizontal-axis turbine is being developed by NENU, which is other project supported by NKTRDP. It is also planned to put the device into water in 2011.

3.4. OUC

OUC started studies of tidal current with a grant from the "863" Program in 2006. It developed a new type of tidal current conversion device, flexible vane turbine. One of the most striking differences of the novel device from the existing ones is the use of flexible vanes, which are made of flexible materials. One possible structure of this turbine can be seen in Fig. 9. Compared with traditional rigid vanes turbines, which are specially designed and manufactured by professional processing technology, it has some advantages, such as simple structure, light weighted, easy to manufacture and convenient to maintain, especially used in huge tidal stream power station with large-sized installed capacity. Furthermore, it may be an environmentally friendly device. As a nonmetallic material, it does not need to be painted against the corrosion action of sea water, avoiding the potential risks of pollution. Meanwhile, flexible vane does not have sharp edge like rigid blades of traditional turbines avoiding the collision risks between marine renewable energy devices and marine animals, such as mammals, fish and diving birds during the fast rotation of the blades tip, which are of marine animals' collision leading concern.

According to some water tank tests of flexible vane turbine [60–62], flexible vanes turbine also has outstanding hydrodynamic characteristics. Firstly, the flexible vanes turbine is a bidirectional turbine, which means it can rotate in a certain direction depending on the fixation of the blades on the turbine, even when tidal currents reverse direction. Secondly, it can start rotating at a low flow velocity. Finally, it can get a higher coefficient of power at a lower TSR, which reduces the rotational velocity of vanes tip, leading to the reduction of the risks of injurious collision, too.

The first demonstration system, a floating, moored platform, that holds a flexible vane turbine with a rated power of 5 kW, was deployed in Zhaitang Island Channel in November 2008, as shown in Fig. 10. Results show that the turbine performed well, generating the power predicted [63–65].

Though great advancements have been achieved in the study of tidal current energy utilization, technologies in China are still far from maturity. There are many problems including high cost, poor stability and small-scale systems besides the common technology challenges in the development of tidal current, such as loadings, operation and maintenance [12]. An in-depth explanation of which need to be carried out in the development of tidal current conversion devices in China is listed as follows:

- Solve the issues regarding design, manufacturing, installation, operation and maintenance of devices in a harsh environment in

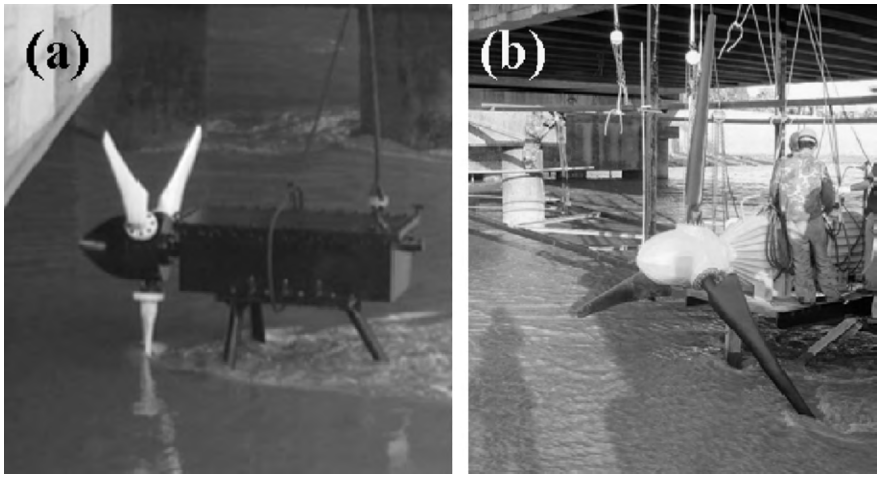


Fig. 7. Devices developed by ZJU, (a) 5 kW horizontal-axis tidal current turbine (2006); (b) half-direct horizontal-axis tidal current turbine (25 kW, 2009).

order to install a demonstration system which can survive a long time (even more than a year).
- All the research organizations should enhance the technology cooperation and intercommunion to set up a platform such as the European Marine Energy Center (EMEC) [66], then all the new concepts can be tested under the same standards and the results can be compared in order to make a selection from the concepts.
- The costs associated with the devices over a life-cycle need to be taken into account to make the technology economically viable.

4. Opportunities

4.1. Exhausting fossil fuels and increasing demand for energy

There is an increasing attention on our dependence on fossil fuels, such as the fact mentioned by Dahai et al. [67] that the traditional fossil fuels in China will be exhausted in few decades (oil, 2040; gas, 2060; coal, 2300). But along with the socio-economic growth of nearly 10% per year, the demand for energy and electricity has been rapidly increasing in China [68]. In 2005, the total China consumption of commercial primary energy sources was estimated at 2247 M tonne of coal equivalent (Mtce), about 62% above 2000 levels, or an average of 10.15% per year, as shown in Table 2 [69]. From Fig. 11, the time-evolution of the electric-power consumption in China during the last 10 years (data 2000–2004 come from Ref. [68] and others come from the annual report on China power industry.), it can be seen that there is a remarkable increase in electricity demand of China with an average above 10% from 2000 to 2007, and even in the global recession, 2008 and 2009, the growth rate reaches about 5.23%, 5.96%, respectively.

It is a real harsh situation for China government, while it may be the biggest opportunity for renewable energy sources. In a country with vast sea area and continuous coast line of 18,000 km, even if a little portion of the abundant tidal current energy were exploited, a big amount of portion of energy needs would be met.

4.2. Increasing pressure on reducing emissions

Today, we cannot live without energy, just as Selcuk et al. said [3] that we each use energy every day: heating, cooking, lighting, TV, commuting, working, shopping etc, and almost every activity requires energy. But at present, the fossil fuels contribute to about 3/4 of the world's energy demand, which emit greenhouse gases-the prime cause of climate change [3]. The increasing emphasis on

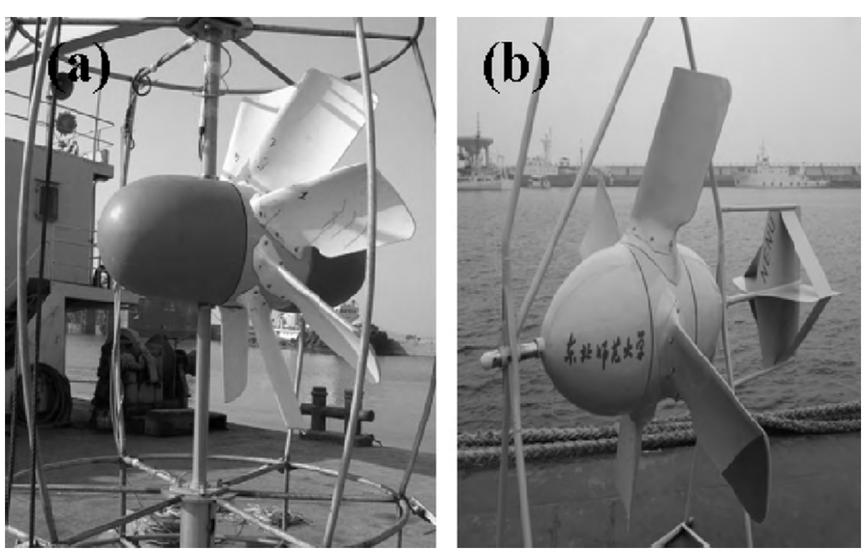


Fig. 8. kW-level tidal current turbines tested by NENU, (a) 1 kW device with low-speed current (2006); (b) 2 kW device for surface tidal current (2009).



Fig. 9. Flexible vane turbine.

control atmospheric emissions of greenhouse and other gases and substances leads to an agreement of all the countries.

China has made intensive efforts in energy conservation and pollution reduction in recent years. By the end of 2009, China's energy consumption per unit of GDP had dropped by 13% from the 2005 level, equivalent to reducing 800 million tons of CO_2. At last year's Copenhagen Climate Change Summit, a new target was set, a much higher target of reducing its emissions per unit of GDP by 40–45% below 2005 levels by 2020. Chinese Premier Wen Jiabao addressed again and again that China will work hard for this target, just as he said in the speech at Copenhagen, "We will honor our word with real action. Whatever outcome this conference may produce, we will be fully committed to achieve and even exceed the target."

But to reduce emissions on such a large scale and over such an extended period of time will require tremendous efforts. The only possible approach to accomplish this goal is to introduce incentives, in the form of low cost financing, tax relief and R&D support, to attain the maximum utilization potential of renewable energy and increase their role in the energy structure as possible as we can. In light of this, it is likely that the interest in renewable energy (of course including tidal current energy) in China will increase dramatically in coming years.

4.3. National policies

China has formulated various strategy measures to accelerate the development of renewable energy technologies. A chronology of events concerning renewable energy (including the public policies and plans) is listed in Table 3.

It can be seen from Table 3, there are so many national policies in China to support the development of renewable energy and in some plans, clear targets were proposed. For example, the medium and long-term China's target, increasing the portion of renewable energy in the final primary energy consumption to 10% by 2010 and 15% by 2020, was set in Medium and Long-Term Development Plan for Renewable Energy in China. It is a difficult task, while it is an opportunity for renewable energy technologies. As one of the promising renewable energy resources, tidal current energy has no choice but to gain a significant development during this period and substantially contribute to the accomplishment of the renewable energy targets.

4.4. The increase of investment on R&D of tidal current energy

4.4.1. Investment from the government

The efforts in research and development in tidal current energy have gained the support of the national financial budget. The government of China supports tidal current energy by establishing R&D plans to fund many R&D projects directly. The main government technology R&D plans include Natural Science Foundation of China (NSFC), National High Technology Research and Development Program ("863" Program) and National Key Technology R&D Program (NKTRDP).

NSFC: Starting in 1990s, the NSFC supported a series of R&D projects in tidal current energy, attracting a lot of universities, national research centers to join in this field. The annual National budget in R&D related to tidal current assigned by NSFC has been

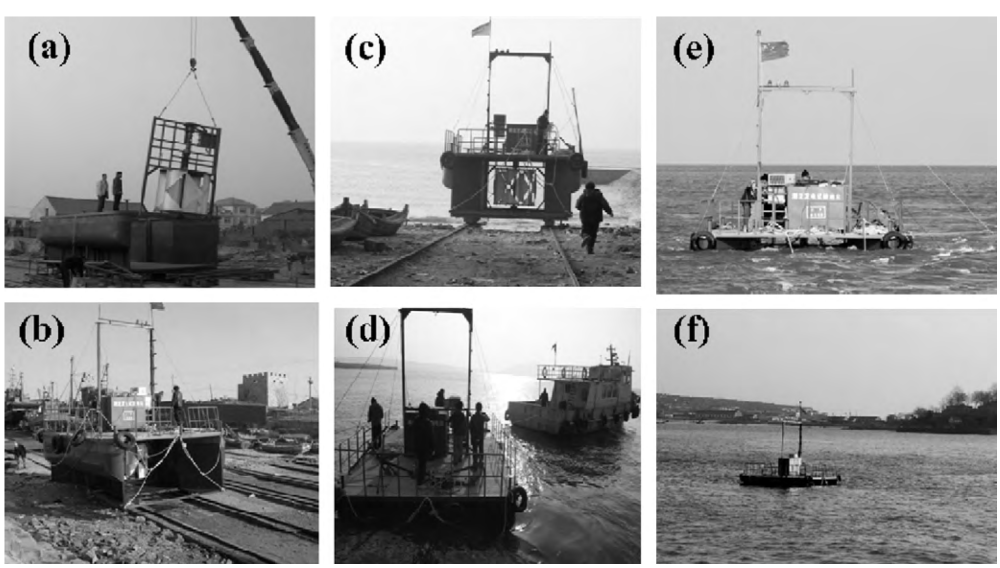


Fig. 10. (a) The floating platform was assembled on a slipway in a shipyard; (b) assembled system; (c) slipped down into the water; (d) towed to the mooring position; (e) test on the sea; (f) overlook of the system at nightfall.

Table 2
Total final energy consumption in *Tenth Five-Year* in China.

Fuel type (energy sources)	Unit	2000	2005	Growth rate 2000–2005 (%/year)
Total primary energy consumption	Mtce	1386	2247	10.15
Coal	Mton	1320	2167	10.42
Oil	Mton	224	325	7.73
Gas	Billion cubic meters	24.5	47.9	14.35
Renewables[a]	Mtce	86	141	10.39

Sources: Ref. [69].

[a] Renewables only includes commercial renewable systems.

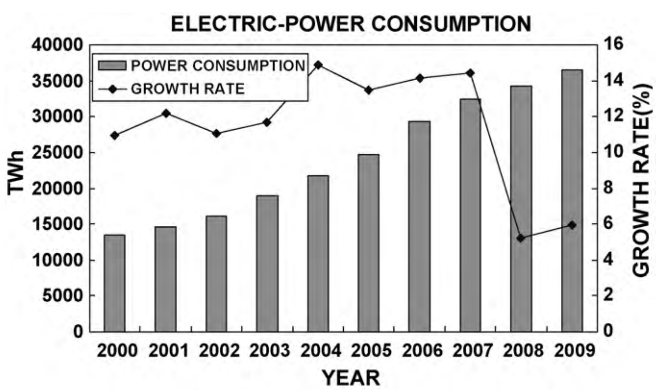


Fig. 11. Time-evolution of the electric-power consumption in China from 2000 to 2009.

increasing sharply recently, which can be seen in a statistical investigation about the annual national budget (from NSFC) of R&D in tidal and wave energy over the period 2001–2007 in [67].

"863" Program: Initiated in March 1986, "863" Program is one of the important national plans regarding basic researches. During the past years, about 10 projects regarding R&D of tidal current energy were supported by 863. The devices described in Section 3 all have benefited from this plan. According to the 12th five-year plan, which is being discussed, more projects will be supported and more money will be assigned (at least 100 million RMB) in next five years.

NKTRDP: NKTRDP initiated in 1982, is the first national S&T program in China, which aims to address major S&T issues in national economic constructions and social development. In 2008, Ministry of Science and Technology announced a Key Projects in NKTRDP titled *Research and demonstration of key technologies in development of ocean energies* in the field of renewable energy. The Key Projects, with a budget of 32 million RMB assigned by the government, includes six sub-projects, and two of them are related to tidal current energy, which are listed as follows:

Table 3
A chronology of events concerning renewable energy in China.

Year	Event	Sector involved	Description
February 2005	Renewable Energy Law	National People's Congress (NPC)	The law requires power grid operators to purchase resources from registered renewable energy producers, and also offers financial incentives, such as a national fund to foster renewable energy development, and discounted lending and tax preferences for renewable energy projects.
May 2006	Interim Measures on Special Fund Management for Development of Renewable Energy	Ministry of Finance	Initiate a national program and provide financial incentives to the renewable energy industry
November 2006	The 11th Five-Year Plan for Ocean Science and Technology Development	State Oceanic Administration MOST; COSTIND; NSFC	The key development task of ocean science and technology regarding renewable energy is to develop and utilize ocean energy, including tide, tidal current, wave and ocean thermal.
April 2007	The 11th Five-Year Plan for Energy Development (2006–2010)	National Development and Reform Commission (NDRC)	During the 5-year period, increase the share of renewable energy technologies in the primary energy production, nuclear 0.1%, hydroelectric 0.8% and other renewable energy resources 0.4% above 2005 levels.
September 2007	Medium and Long-Term Development Plan for Renewable Energy in China (2007–2020)	NDRC	The target is to increase the share of renewable energy in total primary energy consumption to 10% by 2010 and 15% by 2020.
September 2007	International Science and Technology Cooperation Program on New and Renewable Energy	Ministry of Science and Technology (MOST); NDRC	Efforts should be made to develop new patterns for international exchanges and cooperation, encourage countries to complement each other with respective technological strengths, and set up a platform for technological cooperation.
March 2008	The 11th Five-Year Plan for Renewable Energy Development	NDRC	The country's target for the 5-year period (to 2010) is to increase the share of renewable energy to 300 Mtce, which would represent 10% of total energy consumption.
December 2009	Renewable Energy Law (revised version)	NPC	The new law will be put into effect on April 1, 2010. The new law specifies the development and utilization of various renewable energy resources and a renewable energy fund is established for the development of renewable energy resources.

- The study and demonstration on key technologies of tidal current power plant (150 kW).
- The study and demonstration on technologies of tidal current device (20 kW).

4.4.2. Investment from companies

Along with the awareness of the significance of renewable energy, some energy companies in China have shown interest in this field. For example, some energy companies, such as Longyuan Power Group, China Huaneng Group and China Datang Corporation et al., have substantially contributed to the development of wind energy in China. And the biggest traditional energy companies in China, such as Shenhua Group, China National Petroleum Corporation, China Petrochemical Corporation and China National Offshore Oil Corp., are also involved in renewable energy. A renewable program, invested by China National Offshore Oil Corp., concerning tidal current energy is being discussed, which plans to build a demonstration base including tidal current, wave and wind in a isolate island. Therefore, with the join of these big companies, there will be a significant increase of investment in tidal current energy.

4.5. A brief summarization

To be honest, tidal current energy is not the most abundant in the renewable energy resources, even though in the different types of ocean energy, but just like Marten et al. said [7], it is not a matter of either hydropower or wind power, nor of either solar energy or ocean energy, while it is a matter of a little bit of each. In the fight against the society's dependence on fossil fuels, none of the renewable energy resources should be ignored.

5. Conclusions

Tidal current energy will take an important role in the future energy structure due to its various attractive characteristics such as high power density, predictability. There are abundant tidal current resources, several research organizations, which have been working in this field for a few years, and good opportunities in China, so it can be believed that the tidal current energy in China will have a wonderful prospect.

It should be noted that, from the technical point of view, the prospect of China's tidal current is far from optimistic. The tidal current systems which have been installed to date in China are small off-grid tidal current power (<100 kW), and exactly speaking, are on the stage of technical feasibility demonstration. There is so far not any commercial sized installation in this field such as Seagen (one of the best known and largest tidal current energy devices developed by Marine Current Turbines Ltd., which reached its full power capacity of 1.2 MW in December 2008 [70]) to operate for a long time, not to mention the factual utilization of tidal current energy in the form of electricity. So the priority for tidal current energy in China is to demonstrate the survivability and reliability of the devices, even a small capacity device, in order to inspire the researchers and take a substantive step. It is heartening that the work in China is moving forward along the right way.

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